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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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DISPERSION OF GIPSY-MOTH LARVÆ BY THE WIND.[1]

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INTRODUCTION.

The territory infested by the gipsy moth (*Porthetria dispar* L.) is gradually increasing in area, and since isolated colonies are being found each year in woodlands and orchards remote from lines of travel, the question as to their origin has become more urgent. Many agencies assist in the transportation of the moth in its various stages, but as previous experiments proved that small caterpillars are borne by the wind, it seemed desirable to ascertain to what extent this occurs and the maximum distance they may be blown under field conditions. Much depends upon this factor in diffusion, when devising methods of preventing the spread of this pest, and as a practical result of previous experiments tanglefoot has been used extensively in colonies located in the outside infested towns. Trees are banded with tanglefoot to prevent the small larvæ from ascending to the tops, and thus the chances that these larvæ will be blown long distances are decreased.

[1] An extended report on one of the important phases of gipsy moth control work, conducted under the direction of the Bureau of Entomology, L. O. Howard, Chief, and in cooperation with the various States affected.

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To secure further information, the writer, under the direction of Mr. A. F. Burgess, commenced a series of experiments in the spring of 1913 and continued them throughout the following year.[1]

PREVIOUS INVESTIGATIONS ON DISPERSION OF THE GIPSY MOTH.

Many investigations of various sources of spread of this insect were conducted during the early nineties by Forbush and Fernald and published by the Massachusetts State Board of Agriculture in 1896. It was found that frequent teaming in and out of the original infested areas (Medford, Boston, and towns closely surrounding) by vehicles transporting larvæ that dropped from infested shade and roadside trees was largely responsible for the general local spread during those years. It was also suggested that the larvæ were occasionally transported by the wind to distances of perhaps 100 yards, but no further observations were made at that time to substantiate this theory. Numerous ways and means of local spread, such as by birds, animals, and man, are treated in this valuable report.

In the spring of 1910 Mr. A. F. Burgess began a series of experiments on dispersion of the gipsy moth the account of which is published as Bulletin 119 of the Bureau of Entomology. A few small experiments were made in the laboratory by releasing silk-suspended first-stage gipsy-moth larvæ in front of an electric fan, and it was found that they soared to a distance of 20 to 30 feet in the air before falling. This led to more extensive experiments conducted under out-of-door conditions. Screens constructed of poultry wire and covered with tanglefoot were stationed at given distances from sources of infestation and watched for catches of larvæ. On a small screen stationed on the marshes near Lynn, Mass., newly hatched larvæ were caught that had been carried 1,833 feet by a west wind at a velocity of 7 to 19 miles per hour.

Numerous records were compiled to show the relation of temperature, wind velocity, and wind direction to the general trend of spread as it has progressed from the original center, Medford, Mass. It was clearly demonstrated that the prevalent southwest winds following the hatching period of the eggs each year has resulted in the more rapid dispersion of the moth to the northeast than in any other direction. Large woodland areas were scouted in various towns, the data of which were compiled and show the extent to which the wind is responsible for the remote and numerous colonies located. The automobile is also included in this report, as a very important factor in carrying the caterpillars both locally and for long distances.

[1] The writer is indebted to Mr. L. H. Worthley and Dr. J. W. Chapman for cooperation and helpful suggestions; to Messrs. C. E. Hood, F. W. Graham, and Harry Blaisdell for the collection of field data; to Mr. H. A. Preston for the preparation of photographic illustrations, and to others of the laboratory force who contributed in various ways.

FORMER INVESTIGATIONS OF HAIRS ON SMALL LARVÆ.

The bodies of first-stage larvæ (Pl. I, fig. 1) are provided both dorsally and laterally with two types of hairs, or setæ, namely, short, smooth hairs bearing a vesicle about the middle and very long, slender ones which are covered with spinules. Wachtl and Kornauth in 1893 first described the aerostatic setæ found on the first-stage larvæ of *P. dispar* L. and *Lymantria monacha* L. and designated the balloon-shaped swellings occurring on these setæ as aerophores. They suggest that these aerophores assist in the dissemination of the young caterpillars through the air.

Prof. Cholodkovsky in 1894 made some investigations and found that the swellings or vesicles shrank in dead larvæ. His discovery tended to weaken the theory that these swellings contain air and to suggest that they may contain a fluid which will naturally dry up after death. He also found that the swellings remained for months in alcohol as full and rounded as in living larvæ, and if the preparation was allowed to dry on a slide the aerophores quickly shriveled. He therefore concluded that they did not contain air but a fluid which was probably poisonous and served as a protection against insectivorous birds.

Igenitzky, a student of Cholodkovsky, in 1897 further studied the glands that give rise to the hairs and verified the findings of the former investigator, who proposed to call the swellings "toxophores." He further states that the rôle of rendering the larvæ more buoyant may better be ascribed to the long thin hairs which resemble the pappus of some plant seeds.

Prof. K. Escherich in 1912 published a résumé of former investigations into the function of the hairs and cites later work by Wachtl and Kornauth in 1907 in which they cling to their former theory of aerophores. The latter found that the vesicles did not contain liquid, as no reaction was noted by immersion in litmus, rosolic acid, or phenolphthalein, indicating that they contained neither alkali nor acid. They did not shrink in alcohol, glycerin, or acetic acid, or excite any capillary action; hence the investigators concluded that nothing but air could be contained in them. Prof. Escherich lays stress on the air refraction noted in connection with these balloons when immersed in glycerin and viewed under the microscope.

T. C. Shcherbakov in 1914 published observations on the gipsy moth in which he deals at length with the function of the hairs on the first and second stage larvæ, and parts of his paper have been translated by Mr. J. Kotinsky of the Bureau of Entomology. Shcherbakov says that the aerophores are not filled with air or gas and that their connection with the glandular cells would indicate that these vesicles are probably filled with a poisonous secretion. Their exceed-

ingly small size, he contends, makes them physically inadequate to sustain the caterpillar in the air. On the other hand, the very numerous, very long hairs which cover the larva, in addition to the wonderful amount of silk it is capable of spinning, point to the general morpho-physiological structure as the factor enabling it to soar.

He compares this ability of the caterpillar with the meaning of soaring as this term is used by V. N. Chitrovo in an epoch-making botanical work on the study of weeds.[1] Soaring is the capability of a body passively to participate in an air current, as if constituting part of it, arising from special characters in the structure of the body. The analogy in function between the wind-borne seed and caterpillar is complete.

Soaring is determined by the coefficient calculated by the following formula:

$$C = \frac{f(\text{cm}^2)}{w(\text{gr})}$$

where C is the soaring coefficient; f, the surface area (in square cm.); and w, the weight (in grams) of the caterpillar. The coefficient of a bare, freshly hatched first-stage caterpillar is 514.285 and Shcherbakov says that it would be more than six times as great if the area of the hairs were included.

Compared with the Chitrovo soaring table of seeds, the coefficient for the first and second stages of the caterpillar places them among the greatest seed soarers. In a slight wind these caterpillars are capable of soaring. The distance they can cover depends on the topography of the country, the character and abundance of vegetation, the mobility of the caterpillar which in turn depends upon the temperature of the atmosphere, and the availability of foods. The soaring coefficient diminishes sharply for caterpillars in the second stage.

This investigator also states that G. G. Jacobson once, while traveling, observed caterpillars flying in masses toward him, despite the fact that he was at least 17 miles away from the nearest forest.

STUDIES OF STRUCTURE AND FUNCTION OF ACUMINATE AND VESICULAR HAIRS.

Owing to the differences of opinion existing as to the structure and function of the hairs covering the bodies of first-stage larvæ, the writer and Mr. C. E. Hood, with the assistance of Dr. J. W. Chapman, made some tests during the winter of 1914–15. The aim of these experiments was to study both the long acuminate hairs and the short ones bearing vesicles. As the results differ somewhat from those of

[1] Atlas von Samen und Früchten der Feldunkraüter aus Mittelrussland. Bul. für angewandte Botanik, wissenschaftliches Organ des Bureau für angewandte Botanik (Monatsschrift), Jahrg. 7, no. 3, 118 p., 16 fig., 13 pl., March, St. Petersburg, 1914.

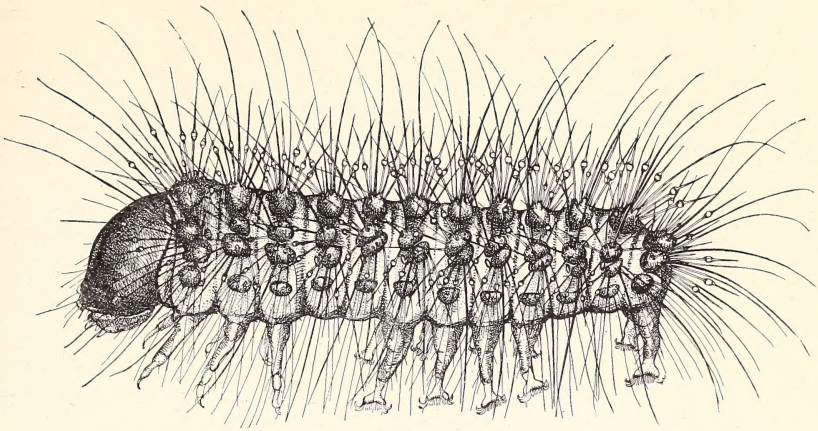


FIG. 1.—FIRST-STAGE LARVA SHOWING TWO KINDS OF HAIRS. (FROM BURGESS.)

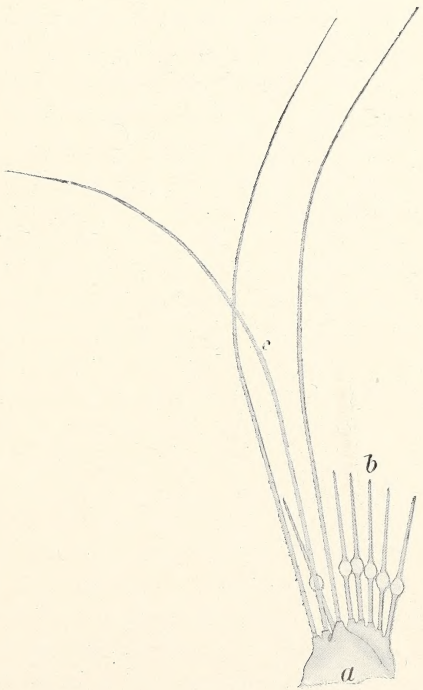


FIG. 2.—*a*, TUBERCLE FROM FIRST-STAGE LARVA SHOWING HAIRS; *b*, VESICULAR HAIRS; *c*, ACUMINATE HAIRS. ALL MUCH ENLARGED. (ORIGINAL.)

GIPSY-MOTH CATERPILLAR SHOWING VESICULAR AND ACUMINATE HAIRS.

previous investigators in that the swellings on the short hairs were found to contain a liquid not yet proven to have toxic properties, it seems advisable that they should hereafter be called vesicular hairs. (Pl. I, fig. 2, *b*.) The term "aerophore" previously applied to the swellings on the short hairs is misleading, as is also the term "toxophore" suggested by Cholodkovsky. The term "acuminate" still applies to the very long slender hairs. (Pl. I, fig. 2. *c*.)

After first-stage larvæ die the swellings on the hairs usually collapse and both air and liquid are present in each type of hair and can be seen under a high-power microscope. A living caterpillar examined in glycerin shows air bubbles occasionally in the hairs and swellings which sometimes extend above and below the latter. The air globules and liquid columns alternate in hairs of dead larvæ, and the difference between the air or colorless liquid present is evident from the typical air refractions in the globular form that air always takes in a liquid; also from the capillary attraction of the liquid contained. Living caterpillars mounted in balsam and examined under a microscope show air bubbles in some of the hairs, but such hairs are exceptions rather than the rule. Caterpillars that have been dead several days show the opposite phenomenon—both air and liquid are seen in them, but air predominates. Some larvæ that had been dead for two years were examined and these contained small short columns of liquid, but air filled the greater portion of the hollow spaces of the hairs. Practically the same was noted in the hairs of an exuvium from a first-stage larva which had also been kept about two years. The vesicles on the hairs had buckled or collapsed and contained air, which was later practically all driven out by heating.

Embryos were dissected from the chorion under balsam and glycerin and then examined in these media. No air globules or what could be termed air refractions were noted in either acuminate or vesicular hairs. Many of the vesicles are only partially distended in this stage. Embryos dissected from the chorion in air contained air globules and columns of liquid alternating in a portion of both types of hairs—probably those ruptured during the dissection.

After some experience it is easy with the aid of a high-power miscroscope to recognize the difference in refractions through the walls of hairs full of colorless liquid or containing globules of air and columns of liquid alternating. The typical liquid refractions are always seen in uninjured vesicular and acuminate hairs. Only rarely are there air refractions noted in either type on living larvæ. A decided change in aspect is noted in dead larvæ after the vesicle begins to collapse, at which time air finds its way into the hairs.

A number of living larvæ were placed under a bell jar which contained a small amount of concentrated sulphuric acid. After six hours many of the larvæ were dead and upon examination a large

portion of the vesicles of the hairs had buckled or partly collapsed. Larvæ still living at this time presented the same appearance to a slight extent. As a check on this experiment, larvæ were killed with chloroform and after 24 hours showed a smaller proportion of buckled or collapsed vesicles, indicating that sulphuric acid took up moisture from the porous hairs.

Sections were made of the larvæ and cells at the base of the hairs studied, but there could be found no indication of the presence of glandular cells. A large trichogen, however, is present at the base of each hair. This would signify that the liquid inclosed in the hairs is not a toxin, as Cholodkovsky suggests, but a mere colorless mobile liquid secreted during the formation of the hairs. The phenolphthalein and litmus-solution tests were also tried, with negative results, further indicating a neutral liquid. The peculiar shape of the vesicular hairs, however, suggests that they may at one time have had a poisonous function but that it has been lost in the present generations.

The results of the experiments and observations indicate that both the normal vesicular and acuminate hairs are filled with a colorless liquid; that the hairs are hollow throughout, and that the vesicles contain the same media as the remaining portion of that type. A few globules of air were seen in hairs of living larvæ which were noted as exceptions. Air partially replaces the liquid after death, following which period the vesicles collapse. It is therefore probable, as Igenitzky and Shcherbakov have indicated, that the acuminate hairs play the greater rôle in making the larvæ more buoyant, as these are from four to six times as long as the vesicular hairs.

SCOPE OF INVESTIGATIONS ON WIND DISPERSION.

In that the main purpose of the following investigations was to secure data on the maximum distance and the extent to which small larvæ are borne by the wind, it was necessary to find conditions where an abundance of larvæ were present in close proximity to treeless areas. These conditions were best afforded along the beaches in Massachusetts and New Hampshire, where there are stretches of marshland from 1 to 2½ miles wide and many miles long. These marshlands are occasionally flooded with salt water and do not contain vegetation favorable to the development of gipsy-moth larvæ. The areas selected for the experiments were to the east of the heavy infestations, thereby getting all the advantages previously known to accrue from the northwest, west, and southwest winds. The Isles of Shoals, off the coast of New Hampshire, afforded ideal conditions in so far as their remoteness from the mainland was concerned and the fact that the country opposite has been infested since 1905. Locations were also selected in the hills of New Hampshire near the

quarantine line for experiments intended to explain the sources of many infestations found under such conditions.

Screens of poultry wire, to which tanglefoot was applied, were erected in three of the selected locations along the coast and on the Isles of Shoals (Pl. II). Those used in the New Hampshire hill experiments were of a somewhat different type and are described under that head. The screens used along the coast (Pl. III, fig. 1) were of ¾-inch mesh poultry wire stapled to 2 by 4 posts which were set in the ground and held in place at the top by guy wires and wooden braces. The posts were 12 feet high and two sections of wire each 75 feet long and 3 feet wide were fastened to these so that the top selvage was 12 and the lower 6 feet from the ground. The screens contained 450 square feet of wire and were built in three 25-foot sections, the middle section facing the west and the other two angling from the ends about 45° to the eastward. This gave the greatest exposure at all times to the northwest, west, and southwest winds. A runway was attached to the posts at the bottom selvage of the wire to facilitate examinations.

HATCHING OF EGGS IN RELATION TO WIND DISPERSION OF FIRST-STAGE LARVÆ.

Close observations on the time of hatching of egg clusters in the field have been kept since 1912 by laboratory men stationed in different sections of Massachusetts and New Hampshire. The data consulted were collected by Messrs. E. A. Proctor in northeastern Massachusetts, J. V. Schaffner, jr., in Massachusetts south and southwest of Boston, and I. L. Bailey in south-central New Hampshire.

TABLE I.—*First, maximum, and last dates of hatching in 1912, 1913, and 1914.*

Year.	Northeastern Massachusetts hatching.			Southeastern Massachusetts hatching.			South-central New Hampshire hatching.		
	First.	Maximum.	Last.	First.	Maximum.	Last.	First.	Maximum.	Last.
1912.....	May 2	May 11	May 22	May 1	May 15	May 25	May 1	May 14	May 23
1913.....	Apr. 25	May 5	May 27	Apr. 26	May 10	May 21	Apr. 29	May 8	May 14
1914.....	May 11	May 15	May 28	May 9	May 15	May 23	May 11	May 16	May 28

The first larvæ were caught on the screen in northeastern Massachusetts May 9, 1913, and the last June 5, while the largest numbers were removed between May 14 and June 1. During 1914 in the same section the first larva was caught about May 16, while the largest numbers were removed from May 20 to May 27 and the last June 6. One larva was caught in Henniker, N. H., as late as June 13, 1914.

In a year of normal hatching, as in 1913, wind dispersion was noted about two weeks after first hatching and one week after hatch-

ing was completed. In 1914 there was an abnormally late spring, which shortened the hatching season, and wind dispersion was noted about one week after the first date and continued about the same period after the last was observed. The total period over which windspread may be expected is from 27 to 30 days in a normal spring, and from 18 to 20 days during a late spring. Ordinarily the maximum dispersion is effected during 10 to 15 days of high temperatures and favorable winds.

LONGEVITY OF FIRST-STAGE LARVÆ AFTER BECOMING ENTRAPPED IN TANGLEFOOT.

In connection with the experiments conducted by using tanglefoot on screens to catch caterpillars blown by the wind, it became essential to know about how long they would live after becoming entangled. As a test, tanglefoot was smeared at various depths on heavy paper and 100 caterpillars dropped into these. Examinations were made at intervals from the time the experiment was started, and it was noted that after three hours practically all were living; after six hours only two were attempting to move, and these were in a very thin smear. After eight hours 65 were dead, and 35 showed signs of life when disturbed. The following morning, after 24 hours, all were dead except seven, and these were in very thin smears, which had little effect upon them.

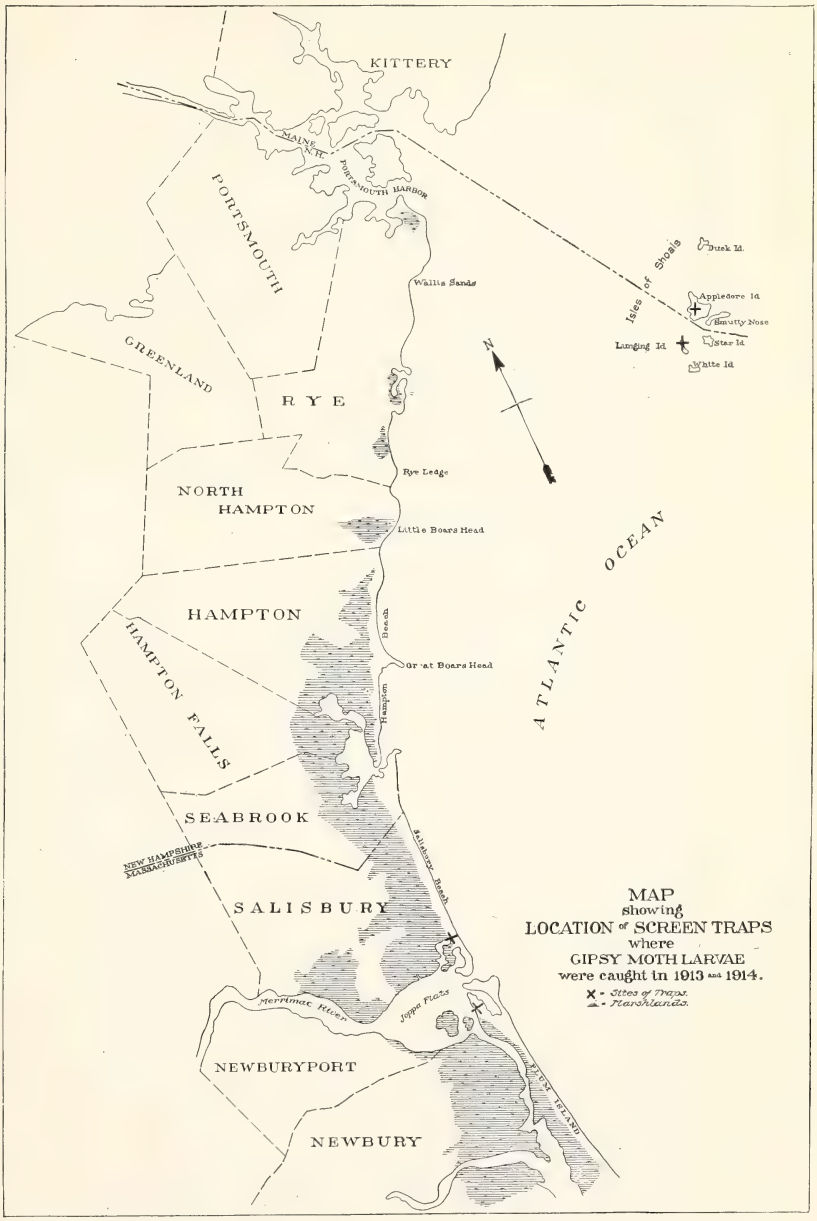
The length of life depended upon the density of the tanglefoot in which they were placed. If the caterpillars in attempting to free themselves became submerged below the spiracles, which often happened in 3 to 5 hours, they died shortly after. As a result, caterpillars lodged in globules of tanglefoot on the screens died in 4 to 6 hours, while those in very thin spots lived 24 or more.

SCREEN EXPERIMENTS AT SALISBURY BEACH, MASS., IN 1913.

April 24, 1913, a large screen (Pl. III, fig. 1), as described, was erected on the edge of the marsh area near the beach, on a site which was 1 mile distant from infested woodlands to the northwest, $1\frac{1}{8}$ miles to the west, and $2\frac{1}{2}$ miles to the southwest. The area to the east, composed of sand dunes, contained small amounts of vegetation, on which gipsy moths could thrive, but this was properly scouted and cleaned for an experiment on reinfestation by the wind.

The temperature, wind direction, and wind velocity were taken each day at alternate hours from 9 a. m. to 5 p. m., and the screen was examined most days when the winds were fair for windspread from the west. Mr. F. W. Graham was in attendance at this screen and made many of the following observations and notes.

No larvæ were blown on the screen, which was one-fifth mile from the ocean, by winds coming directly from the east. Larvæ were



MAP SHOWING LOCATION OF SCREEN TRAPS WHERE GIPSY-MOTH LARVÆ WERE CAUGHT IN 1913 AND 1914.

FIG. 1.—SCREEN AT SALISBURY BEACH, MASS., WHERE 266 LARVÆ WERE CAUGHT DURING MAY AND JUNE, 1913, AND 96 IN MAY, 1914. SHOWING BEACH AND OCEAN IN BACKGROUND. (ORIGINAL.)

FIG. 2.—SCREEN AT PLUM ISLAND, MASS., WHERE 42 LARVÆ WERE CAUGHT IN MAY, 1914. NEWBURYPORT IN BACKGROUND 2 MILES WEST—NEAREST INFESTED TREE GROWTH IN THAT DIRECTION. (ORIGINAL.)

SCREEN TRAPS FOR WIND-BLOWN GIPSY-MOTH LARVÆ ON MASSACHUSETTS COAST.

borne, however, by northeast and southeast winds from beach infestations 1 mile or more distant. This screen was inspected in May by Dr. Howard and Dr. Paul Marchal.

TABLE II.—*Dates and numbers of newly hatched caterpillars caught on screen, with temperatures, direction of wind, and velocity of wind, at Salisbury Beach, Mass., in 1913.*

Date and time removed.	Number of caterpillars caught.	Maximum temperature.	Minimum temperature.	Average between 9 a. m. and 5 p. m.	
				Prevailing wind direction.	Wind velocity, in miles per hour.
		°F.	°F.		
May 8	(1)	54	49	S. and SE.	11 to 15
May 9, p. m.	2	62	52	W. and SW.	8 to 11
May 10	(1)	49	44	NW.	18 to 22
May 11, a. m.	3	57	50	NW.	15 to 18
May 12	(1)	60	56	NW. and SE	8 to 11
May 13	(1)	70	59	SW.	10 to 13
May 14, a. m.	19	68	62	NW.	13 to 17
May 15, a. m. and p. m.	71	64	49	W. and SW.	7 to 9
May 16, p. m.	15	44	42	NE.	8 to 12
May 17, p. m.	13	54	50	E. and NE.	8 to 12
May 18	(1)	(2)	(2)		
May 19, p. m.	25	64	58	W. and NW	18 to 23
May 20, p. m.	30	66	55	NW. and W.	15 to 20
May 21, p. m.	10	60	51	SE.	8 to 12
May 22	(1)	52	48	E. to NW.	6 to 8
May 23, p. m.	12	58	54	NW., SW., and E.	2 to 5
May 24	(1)	56	52	N. to E.	7 to 10
May 25	(1)	53	51	E. and SE.	7 to 11
May 26, p. m.	16	59	57	NW to E.	6 to 10
May 27	(1)	51	48	E.	8 to 12
May 28	(1)	48	47	NE.	8 to 11
May 29	16	64	53	NW.	19 to 23
May 30, p. m.	3	72	64	W. and NW.	17 to 21
May 31, p. m.	11	76	62	NE to NW.	8 to 12
June 1, a. m. and p. m.	18	77	62	SE to SW.	16 to 20
June 2, p. m.	0	72	62	NW.	16 to 20
June 3, p. m.	1	79	72	SW.	15 to 19
June 4, p. m.	0	62	56	NW. to E.	12 to 16
June 5, p. m.	1	70	62	E. to S.	7 to 11
Total	266				

[1] No examination. [2] No records.

It will be noted from Table II that 266 caterpillars were caught on 450 square feet of wire, and most of these on days when the winds blew from the northwest, west, or southwest, namely, May 14 to 19, May 15 to 17, May 19 to 25, May 20 to 30, etc., while fewer were caught when the wind was from the northeast and southeast. This may be explained by the light infestations 1 mile or more to the northeast and southeast; also it will be noted that winds from these directions along the coast are accompanied by much lower temperatures, at which time the caterpillars spin less actively.

Many of the small larvæ were taken on the posts and crosspieces of the structure; thus of the 25 caught May 19, 18 had lodged in this manner and were living when removed. Others were swinging by threads on the east side of wire, where they had blown through the mesh from the west, the threads having caught in tanglefoot.

The first larva was caught May 9 and the last June 5, although examinations of later date were made. These dates indicate the range of the wind dispersion period for that section in 1913. The distance borne by the wind was 1 mile or more.

Another small experiment was conducted 200 feet from the above screen by attaching to the northwest, west, and southwest sides of a small stable 77 square feet of cotton cloth which was smeared with tanglefoot. This experiment was not started at the beginning of the season, but 9 larvæ were blown into the tanglefooted cloth between May 20 and 31. The object in this experiment was to ascertain the comparative efficiency of tanglefooted wire screen and a solid tanglefooted surface as traps.

CONTINUATION OF SCREEN EXPERIMENT AT SALISBURY BEACH, MASS., IN 1914.

The same screen (Pl. III, fig. 1) as was erected in 1913 was cleaned and retanglefooted for the dispersion season of 1914. The infestation in the woodlands to the westward, owing to the increase of *Calosoma sycophanta* L., *Compsilura concinnata* Meig., and the wilt disease, was less intense during the latter year. The dispersion period was much later and consequently much shorter than in 1913. Examinations were begun about the time the hatching of eggs was first noted in the field. The first caterpillar was caught May 19 and the last May 31 in this location.

The weather records were taken 1 mile south for this point at Plum Island, Mass. (Pl. II), by Mr. C. E. Hood, and were compared with those of the United States Weather Bureau at Boston, Mass., from which they differed very little.

TABLE III.—*Dates and numbers of newly hatched caterpillars caught on screen, with temperature, direction of wind, and velocity of wind, at Salisbury Beach, Mass., in 1914.*

Date and time removed.	Number of caterpillars caught.	Maximum temperature.	Minimum temperature.	Average between 8 a. m. and 5 p. m.	
				Prevailing wind direction.	Wind velocity, in miles per hour.
		°F.	°F.		
May 19, a. m.	1	78	64	W. and NW.	8 to 12
May 20, a. m.	7	81	66	W. and NW.	2 to 6
May 21, a. m. and p. m.	32	60	53	NE. to SE.	7 to 11
May 22, a. m.	0	60	55	E. and SE.	2 to 10
May 23, a. m. and p. m.	12	78	65	W.	10 to 23
May 24, a. m. and p. m.	14	75	64	W.	11 to 16
May 25, a. m.	7	75	61	SW.	12 to 21
May 26, a. m.	10	89	75	SW. and W.	7 to 20
May 27, a. m.	5	94	79	W. to S.	4 to 12
May 28, a. m.	1	82	75	NW.	11 to 20
May 29, a. m. and p. m.	4	66	56	E. and SE.	9 to 17
May 30, a. m.	2	76	60	SW.	7 to 9
May 31, a. m. and p. m.	1	84	77	W.	7 to 14
Total	96				

In all 96 larvæ were trapped during the season, most of which were removed on days when the wind blew from the west, southwest, or northwest. The largest catch was removed May 21, at which time the wind blew from the northeast and southeast, but it was evident that most of the larvæ were caught May 20 in the afternoon, as the screen was not examined during that period. There was less source of spread from the northeast and southeast along the ocean shore than from the westward points. On May 21 the temperature ranged from 53° to 60° F., at which time there was reasonable activity among the caterpillars.

One should not fail to note that spread was secured from all directions from which the wind blew except from the east, and the infestation at this point was almost obliterated. No north winds were noted during the hourly observation periods.

SCREEN EXPERIMENT CONDUCTED ON PLUM ISLAND, MASS., IN 1914.

April 14, 1914, a screen (Pl. III, fig. 2) was erected on the edge of the marsh near the Merrimac River. It was of the same size and proportions as that erected 1 mile farther north, at Salisbury Beach. The shrubbery, composed mostly of beach plum, bayberry, wild rose, sumac, poplar, and willow, on the north end of the island, was examined for egg clusters and these were creosoted. This practically obliterated the source of infestation to the eastward of the screen.

The location of the screen (Pl. III, fig. 2) was such that it was 2 miles from infested woodlands across the marshes and Merrimac River to the northwest, west, and southwest. Frequent examinations made it possible to determine the direction from which all the caterpillars came. It is not supposed that all the caterpillars caught during the time west winds prevailed came from the nearest infestations (2 miles), but in some instances 5 miles or more. There was, however, a small infestation on a few roadside willows 1 mile to the southwest, but these were so thoroughly cleaned and tanglefooted in the spring that no caterpillars could be found on them during the dispersion season. The woodland infestation was 1 mile beyond this, totaling 2 miles from the screen.

Mr. C. E. Hood attended the screen, making three or four examinations for larvæ daily from May 10 to June 13. The temperature, wind direction, and wind velocity were recorded hourly each day from 8 a. m. to 5 p. m., inclusive.

TABLE IV.—*Dates and numbers of newly hatched caterpillars caught on screen, with temperatures, direction of wind, and velocity of wind at Plum Island, Mass., in 1914.*

Date and time removed.	Number of caterpillars caught.	Maximum temperature.	Minimum temperature.	Average between 9 a. m. and 5 p. m.	
				Prevailing wind direction.	Wind velocity, in miles per hour.
		°F.	°F.		
May 20, a. m. and p. m.	8	81	66	W. and NW.	2 to 6
May 21, a. m.	4	60	53	NE. to SE.	7 to 11
May 22, a. m.	1	60	55	E. and SE.	2 to 10
May 23, a. m. and p. m.	14	78	65	W.	10 to 23
May 24, a. m. and p. m.	7	75	64	W.	11 to 16
May 25, a. m. and p. m.	5	75	61	SW.	12 to 21
May 26, p. m.	1	89	75	SW. and W.	7 to 20
May 27, p. m.	1	94	79	W. to S.	4 to 12
May 28, p. m.	1	82	75	NW.	11 to 20
Total	42				

A total of 42 caterpillars were removed from this trap between May 20 and May 28—a very short season in comparison to the records at Salisbury Beach in 1913. Five of these larvæ were blown on the screen by winds from the east and south, while the remaining 37 came with the winds from the west. Larvæ were caught during the morning of May 20, when the velocity of the wind for that period ranged from 2 to 4 miles per hour, and on the following day, when the temperature ranged from 53° to 60° F.

SCREEN EXPERIMENT ON ISLES OF SHOALS, N. H.

The Isles of Shoals (Pl. II), located 6 miles off the coast of New Hampshire and Maine, was selected as an ideal place in which to establish a trap for tests in long-distance spread. An elevated spot on Appledore Island was chosen and a screen erected in April, 1913. It was not known at that time that Appledore, comprising about 100 acres, was infested, but subsequent scouting in the summer showed that this was the case. This island contains a varied growth of low shrubbery, some of which is very favorable food for gipsy-moth larvæ, but the infestations were slight and covered small areas well scattered over the territory.

The screen was examined at intervals during that year from May 1 to June 3 and 14 first-stage larvæ were removed during that period. Some of these larvæ were alive on removal and were taken on days when the wind blew directly from the mainland, which indicated that many of them came from that source, but there was room for question because the island on which the screen was located in 1913 was later found infested.

To eliminate any possibility of error in drawing conclusions another island in this group, namely, Lunging, was selected for the experiment in 1914. It is the most western of the isles and located so as to

FIG. 1.—SCREEN ON LUNGING ISLAND, ISLES OF SHOALS, N. H., ON WHICH 57 LARVÆ WERE CAUGHT DURING MAY, 1914. OCEAN IN BACKGROUND. VEGETATION IN FOREGROUND IS UNFAVORABLE FOOD FOR THE LARVÆ. (ORIGINAL.)

FIG. 2.—SCREEN ON HOLTS HILL, HENNIKER, N. H., WHERE TWO LARVÆ WERE CAUGHT IN 1914. (ORIGINAL.)

SCREEN TRAPS FOR WIND-BLOWN GIPSY-MOTH LARVÆ IN NEW HAMPSHIRE.

receive the full force of the northwest, west, and southwest winds directly from the mainland. This island is composed mostly of bare rock, with small patches of soil. There is little favorable vegetation for gipsy-moth larvæ, and three careful examinations made in the spring of 1914 revealed no egg clusters.

Four hundred and fifty square feet of wire screen was used, and an extra screen was made of cotton cloth tacked to a frame 40 feet long and 3 feet wide, and tanglefoot applied. It was anchored at an incline on the rocks, facing the west.

On this island there is one cottage which afforded quarters for Mr. Harry L. Blaisdell, who was in constant attendance at the screen (Pl. IV, fig. 1). Arrangements were also made with the United States Life-Saving Service for transportation to and from the islands on their regular trips to Portsmouth, N. H. Mr. Blaisdell recorded the weather conditions hourly from 8 a. m. to 5 p. m., using a compass, thermometer, and hand anemometer. He also examined the screens continuously and made careful notes on the time and wind conditions when each caterpillar was caught, which made it possible to determine the source from which it came. Practically all the larvæ found on the screens were alive, and in most cases they were removed very soon after entanglement.

TABLE V.—*Number of caterpillars caught at Lunging Island, Isles of Shoals, N. H., in 1914, with direction and distance from which they came.*

Date.	Other islands of the Isles of Shoals, E., NE., SE., and S., ¼ and ⅝ mile.	Kittery, Me., NW., 7 miles.	Wallis Sands and Rye, N. H., WNW., 6 miles.	Rye Ledge and Little Boars Head, N. H., W., 7 miles.	Seabrook, New Hampshire, and Massachusetts line, WSW., 11 miles.	Plum Island (north end), Mass., SW., 13½ miles.
1914.						
May 20	6	1				
May 21	6					
May 22	1					
May 23			8	3		
May 24			20		1	
May 25	7					9
May 26	2					
May 31	1					
June 1	1					
June 2	1					
Total	25	1	28	3	1	9

Sixty-seven larvæ were removed from the screen and cotton cloth between May 20 and June 2. The wind data given in the table were taken on the island, but comparison was also made with the records taken at Plum Island, Mass., 13½ miles to the southwest. It was thought that the air currents on the shore of the mainland where most of the small larvæ were picked up would be much changed from their course before reaching the islands, but only slight differences were noted by the two observers during the period.

It will be noted, according to the records taken on Lunging Island, that nine larvæ came from the southwest, that is, from Plum Island, 13½ miles away. The weather records at the latter place indicate that conditions were such that at least 18 of those caught on the screen at Lunging Island came from Plum Island, or more distant points in that direction.

Thirteen and one-half miles is the maximum record for distance that larvæ have been carried by the wind in all experiments thus far conducted by us, yet it is probable that the limit has not been reached. The locations for securing such records, together with suitable conditions with reference to infestations, are rare.

DISPERSION EXPERIMENTS ON THE HILLS OF NEW HAMPSHIRE IN 1913 AND 1914.

In the scouting operations conducted by Mr. L. H. Worthley in the outside territory infested by the gipsy moth, numerous infestations were being found on hilltops. It could not be ascertained whether this spread was the result of the wind, vehicles, or other possible carriers—man or animals. These hills contained woodlands, orchards, pastures, mowings, and roads over which there was more or less travel, making spread possible artificially. Thinning was practiced in these infestations, egg clusters were creosoted, and bands of tanglefoot were placed on the trees to keep the first-stage caterpillars hatching near the ground from ascending the trees, thereby decreasing their chances of spread by the wind.

To investigate the source of these hilltop infestations, one hill was selected in each of four towns in New Hampshire, namely, Andover, Henniker (Pl. IV, fig. 2), Hillsboro, and Troy, and large screens erected thereon as traps for the small caterpillars. (See also Plate VII.) It seemed desirable to know if these colonies were the result of windspread, and whether caterpillars were being carried from hilltop to hilltop, valley to hilltop, or vice versa, so that scouting and control methods could be changed accordingly.

The screens were constructed of ⅝-inch mesh poultry wire 3 feet wide. This was stapled to posts set in the form of a T. The posts were about 12 feet high and guyed with No. 13 wire. The wire was fastened in two widths, one above the other, making a screen surface 6 feet wide. The top selvage ranged from 10 to 12 feet from the ground owing to the level of the land. The screens were erected with one wing 35 feet long, facing the north and south, and another, 40 feet long, facing east and west. The total number of square feet exposed to the winds in each screen was 450.

There were known infestations one-third to two miles in all directions from the screens in the foregoing towns, but negative results were

secured on those at Hillsboro and Troy, N. H., the infestations in the neighborhood of which were fewer and at longer distances.

In 1912 several large gipsy-moth colonies were found in Andover and Henniker, N. H. On Beech Hill, Andover, about one-third of a mile from where the screen was erected, over 30,000 larvæ were destroyed in the summer of 1912. This colony and surroundings were carefully treated, so that the infestation was nearly exterminated in 1913 and 1914. All the smaller colonies found in the town also received thorough treatment. Similar conditions prevailed in Henniker.

The screens were examined at periods during the dispersion season of 1913 and 1914. No positive results were secured during the first year, but one living larva was removed from the Andover screen May 27, 1914, at 2 p. m.

May 26, 1914, a dead larva was removed from the Henniker screen and a living specimen June 13, together with the molted skin of a second-stage larva. It is difficult to state from which direction the first larva was blown, but the second came from the northwest or west as the wind blew from those directions during the two days previous.

The 3 first-stage larvæ caught on the Andover and Henniker screens in 1914 proved conclusively that the dispersion among the hills is brought about most extensively by the wind. This is more emphatic when one considers the small air space covered by these traps and the small sources of infestation in these localities.

ALTITUDE EXPERIMENT WITH AVIATION OF SMALL CATERPILLARS.

At the close of the season's work in 1913, after securing some fair records on the distance that larvæ are borne by the wind, it seemed advisable to get data on the possible altitude they reach during their transportation. After numerous inquiries and investigation a suitable place for such an experiment was found in Merrimac, Mass. (Pl. VII). This consisted of the standpipe (Pl. V, fig. 1) for the storage and pressure of the town water. It is located on a small hill 240 feet above sea level, and permission to erect a small wire screen on the top of the tank was obtained from the selectmen of the town.

The tank was 55 feet high from the level of the summit of the hill and a screen of $\frac{3}{4}$-inch mesh poultry wire was stapled to upright 2 by 4 posts 5 feet long. The top selvage of the wire (Pl. V, fig. 2) was 5 feet above the top of the tank, totaling 60 feet above the ground. The screen was 36 feet long and contained 144 square feet, while the tank was 40 feet in diameter, allowing ample space for the examiner to get around the ends. It was set up so that the sides faced the east and west.

Near the tank were a few low trees consisting of white pine and gray birch; these were cleaned of egg clusters and the trunks tangle-footed in order to prevent the larvæ resulting from overlooked egg clusters getting into the tops of the trees. The country about this hill on all sides is generally infested (Pl. VI), so that almost all winds tempered to 50° F. or above bore caterpillars. The weather data used for comparison with the daily catch here was taken at Plum Island, about 10 miles east.

TABLE VI.—*Dates and numbers of caterpillars removed from screen at Merrimac, Mass., in 1914; also general direction of the wind during the period.*

Date and time removed.	Number borne by west winds.	Number borne by east and south winds.	Direction of wind at time of examinations and a few hours previously.
May 19, p. m	[1] 9	0	NW. and W., 8 a. m. to 5 p. m.
May 20, p. m	22	0	NW. and W., May 19, 8 a. m., to May 20, 2 p. m.
May 21	([2])		
May 22, p. m	0	44	NE., E., and SE., May 20, 3 p. m., to May 22, 5 p. m.
May 23, p. m	8	0	W., NW., and SW., May 23, 8 a. m., to May 27, 10 a. m.
May 24, p. m	32	0	Do.
May 25, p. m	2	0	Do.
May 26	([2])		
May 27, p. m	[3] 12	0	Do.
May 27, p. m	0	[3] 6	Changed to S., May 27, 11 a. m., to 5 p. m.
May 28, p. m	2	0	W. and NW., May 28, 8 a. m. to 5 p. m.
May 29	([2])		
May 30, p. m	2	0	SW. and W., May 30, 8 a. m., to June 1, 11 a. m.
May 31	([2])		
June 1, p. m	1	0	S. and SE., June 1, 12 m. to 5 p. m.
June 2, p. m	1	0	W. and NW., June 5, 8 a. m., to June 6, 5. p. m.
Total	91	50	

[1] Some of these larvæ were caught before this date, as 7 were dead on removal.
[2] No examination.
[3] Number accredited to different winds estimated owing to changes in direction.

One hundred and forty-one larvæ were trapped on this screen of 144 square feet between May 19 and June 2, inclusive. A few of these undoubtedly were blown on before May 19, as seven of the nine were dead on removal, indicating that the aviation of the small larvæ began probably two or more days earlier in Merrimac than along the seacoast.

With apparently an equal infestation on all sides of this screen one-half mile or more distant, almost twice as many larvæ were trapped as a result of prevailing winds from the west as from the east.

The data secured in this experiment indicate that all winds during the day in a section generally infested bear caterpillars excepting the north, which was not recorded during this period. Considering that practically one larva was caught per square foot 300 feet above sea level, it is only by conjecture that we can estimate the maximum height reached by them and the length of time they remain suspended under average conditions. It is a known fact that large numbers of

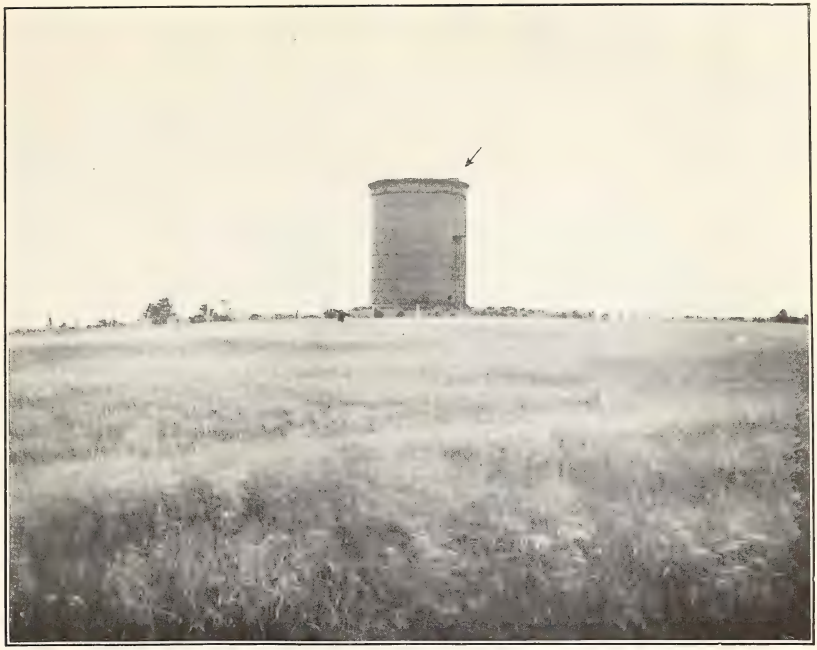


FIG. 1.—SHOWING STANDPIPE, MERRIMAC, MASS. ARROW POINTS TO SCREEN TRAP ON TOP. (ORIGINAL.)

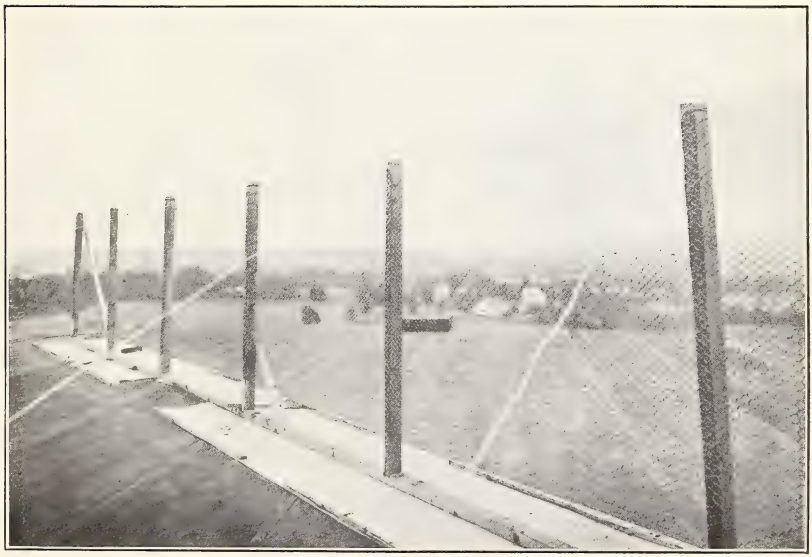


FIG. 2.—SCREEN ON STANDPIPE, MERRIMAC, MASS., AT CLOSE RANGE, WHERE 141 LARVÆ WERE CAUGHT DURING MAY AND JUNE, 1914. (ORIGINAL.)

SCREEN TRAP FOR WIND-BLOWN GIPSY-MOTH LARVÆ, MERRIMAC, MASS.

VIEW FROM TOP OF STANDPIPE, MERRIMAC, MASS., SHOWING SOURCE OF GIPSY-MOTH INFESTATIONS; ALSO YOUNG ORCHARDS WHERE SCATTERING INFESTATIONS WERE LOCATED AS A RESULT OF WIND DISPERSION. (ORIGINAL.)

isolated infestations are scattered in hill and dale over 19,378 square miles of the New England States (Pl. VII), excepting Vermont,[1] and a comparison of such information with the foregoing data at once suggests the source of practically all spread of this species.

OBSERVATIONS ON WIND DISPERSION AT SALISBURY BEACH, MASS., IN 1913 AND 1914.

Salisbury Beach, owing to its separation by extensive marshes from infested woodlands and to the limited amount of favorable food plants for gipsy moths thereon, was selected as a desirable location to be cleaned up and watched for reinfestation. The south end of the beach (Pl. II), 1⅛ miles in length, was scouted and the egg clusters were creosoted in 1913 and 1914. Beach plum was the predominant shrub growing on the sands and was not fed upon by the caterpillars. Bayberry, wild rose, willow sprouts, balsam poplar, and other small growth thrived to a certain extent and are favored food plants.

The scouting in 1913 resulted in the finding of 144 egg clusters distributed over the beach in a few clumps of shrubbery. The control work was followed up during the summer by frequent examinations for caterpillars, which resulted in their discovery in seven or more places other than where egg clusters were located. From one to six caterpillars were found in small isolated clumps of bayberry and wild rose in no less than six spots near which there were no egg clusters. These patches of favorable food afforded good traps for the newly hatched caterpillars, which were being carried from the infested woodlands 1 mile to the west, as did the tanglefooted screen on which such large numbers were caught the same year.

Seventy-seven egg clusters were found and creosoted in 1914 in the same area as was scouted in 1913. Thus it will be noted that there were slightly more than one-half the number of egg clusters found in 1914 as in 1913, in spite of the rigid control measures practiced during the former year. The location of the beach with respect to the infested woodland across the marshes was ideal for heavy reinfestation each year, and this condition prevails in apple orchards, woodlands, and shade trees that are cleaned within the gipsy moth infested area and become reinfested annually by means of the wind.

OBSERVATIONS ON ISOLATED TREES AND YOUNG APPLE ORCHARDS FOR REINFESTATION.

Twelve isolated trees in the midst of cultivated fields and mowings were selected in the early spring of 1914; these were cleaned of egg clusters, trunks tanglefooted, and later examined for reinfestation by the wind. These trees were selected in towns about Merrimac, Mass.,

[1] During the winter of 1914–15 a few small infestations were discovered in Vermont.

where there was a general infestation. Some of them were later discarded owing to the discovery of overlooked egg clusters that had hatched. On the trees retained there were from 2 to 8 and in one case 11 large caterpillars above and below the tanglefoot, indicating that there was reinfestation by the wind. The top of a medium to large sized apple tree would offer more resistance to the wind than did the screen on the Merrimac standpipe, upon which was lodged approximately one first-stage caterpillar to every square foot of wire exposed.

Some further observations confirming these conclusions were made by Mr. C. E. Hood in July, 1914, in two young apple orchards in Merrimac (Pl. VI) and West Newbury, Mass. These orchards were 2 and 4 years old, respectively, and clean cultivation was practiced in them. A large number of the trees were examined in the center of these orchards, which were in some cases 500 yards from the nearest infestations on larger trees. Thirty-four large larvæ were found in selected areas of the two orchards, not more than one of which appeared on a single tree. No egg clusters could be found, and it was concluded that the infestation was due to windspread.

Mr. J. V. Schaffner, jr., has also reported a similar incident from Dover, Mass.

SMALL LARVÆ BLOWN INTO THE OCEAN ANNUALLY FROM INFESTED WOODLANDS NEAR THE COAST.

At the rate of 266 first-stage larvæ caught on 450 square feet of tanglefooted wire at Salisbury Beach in 1913 (being located 1 mile from the nearest infested woodland), a basis is given for estimating the huge numbers borne into the ocean each year. At the same ratio a continuous screen 1 mile long and 6 feet high would have caught 18,726 larvæ. Judging from the altitude, 300 feet above sea level, where quantities were caught at Merrimac, Mass., it is apparent that this number should be fifty times as much, or 936,300 per mile. There is now upwards of 450 miles of coast line infested in New England (Pl. VII), and figuring that general spread by wind occurs over one-half of this distance, the ocean swallows up annually over 210,000,000 small larvæ. The number is probably much greater than is here indicated, as it is not known how many of the small larvæ passed through the wire meshes of the screen which is used as a basis for these figures.

These calculations, which are partly theoretical, serve to indicate what might have been the result with regard to the area infested had the moth first been introduced 100 miles farther westward than Medford, Mass. It also emphasizes the necessity of keeping this moth confined to New England territory, if rapid and general spread over the United States is to be prevented.

FEEDING OF LARVÆ PRIOR TO DISPERSION BY THE WIND.

Several of the first-stage caterpillars of various sizes caught on the screens during 1913 and 1914 were selected and examined for the presence of plant cells in the alimentary tract. As all caterpillars blown any reasonable distance by the wind are newly hatched, first-stage specimens, it is impossible to ascertain from a superficial examination which have taken food and which have not. Before the examinations were made it was necessary to fix the material, stain with eosin and methylene blue, section with a microtome, and mount on slides, and this work was performed at Bussey Institute, Harvard University, under the direction of Dr. R. W. Glaser of the Bureau of Entomology.

Caterpillars were selected during the two seasons which had been borne by the wind a distance of 1, 2, and 6 or more miles, respectively, from the nearest source of infestation. Results were as follows:

TABLE VII.—*Percentages of small caterpillars having fed which were caught on screens during 1913 and 1914.*

Year.	Locality and distance carried by wind.	Number of caterpillars that had fed.	Number of caterpillars that had not fed.
1913	Salisbury Beach, Mass., 1 mile from infested woodland	13	7
	Isles of Shoals, N. H. Infestation in brushland around screen	1	0
1914	Plum Island, Mass.; 2 miles from infested woodland	2	5
	Isles of Shoals, N. H.; 6 miles or more from infestation on the mainland to the westward	7	8
	Merrimac, Mass.; ½ to 1 mile from heavy infestation in all directions	0	2
	Total	23	22

Of the 45 small caterpillars prepared and examined during the two years that experiments were conducted, 23, or 51 per cent, had consumed a very small amount of food, while the remainder, 40 per cent, showed no signs of it.

COMPARISON OF WEATHER DATA BETWEEN PROVIDENCE, R. I., AND AMHERST, MASS., WITH REFERENCE TO DISPERSION IN 1913.

The period in which first-stage larvæ were borne by the wind in 1913 in eastern Massachusetts was from May 9 to June 5, inclusive. After comparing the hourly wind direction from 7 a. m. to 6 p. m. when there was no rain and the temperature was 50° F. or above at Providence, R. I.,[1] and Amherst, Mass.,[1] one notes a slight difference in the total wind movement in the various directions. For instance, in Providence the wind blew from the northwest 92 hours, from the

[1] The weather records at Providence were secured from the office of the U. S. Weather Bureau, and those at Amherst from the Experiment Station.

north 17, from the northeast 22, from the east 3, from the southeast 51, from the south 37, from the southwest 1, and from the west 9 hours during the foregoing period. In Amherst, Mass., it blew for the same period from the northwest 50 hours, from the north 51, from the northeast 9, from the east 2, from the southeast 30, from the south 31, from the southwest 3, and from the west 46 hours.

Providence was first found infested by the gipsy moth in 1901, and during the scouting season of 1913–14 egg clusters were found as far west as Woodstock, Pomfret, and Brooklyn, Conn.—a distance of 36 miles, or an average spread of 3 miles each year. It is apparent that this general infestation was not accomplished by direct east winds, as there are few recorded each year at the proper period, but by a combination of northeast and southeast winds transporting the larvæ in a southwesterly and northwesterly direction from 1 to 10 miles, thus gaining an average of 3 miles each year directly west.

Although this insect has not yet reached Amherst, Mass., in its general sweep across the country, it occurs within a few miles to the eastward. A perusal of the wind records for the dispersion period of 1913 shows three times as many hours of north winds and about one-half as many northeast and southeast winds combined as are recorded in Providence, R. I. The total movement of northwest and west winds, which blow the larvæ back into the infested territory each year, is practically the same in the two localities.

From this data it appears that the increase in the amount of north winds and the decrease in combined northeast and southeast winds at Amherst, when compared with the wind records at Providence, may result in a somewhat more rapid southwestern advance of the insect if it becomes established in the Connecticut Valley. More rapid southern and western spread is likely if the infestation reaches the Central States.

SPREAD OF THE GIPSY MOTH IN NEW ENGLAND.

The gipsy moth was introduced at Medford, Mass. (Pl. VII), in 1869, from which point it has spread gradually over large areas in Massachusetts and other New England States, excepting Vermont.[1] Small infestations have also been located in New York, New Jersey, and Ohio, but these colonies are fast being exterminated. Extensive efforts to prevent spread have been carried on in Massachusetts by the State since 1890, with suspension of appropriations and efforts only from 1900 to 1905. Other infested States have appropriated smaller amounts which have aided in the suppression work. Congress began making appropriations in 1906, and these annual sums have been expended to prevent spread and help control of the gipsy moth and the brown-tail moth.

[1] See, however, footnote on p. 17.

DISPERSION OF THE GIPSY MOTH IN NEW ENGLAND AND AREA QUARANTINED – 1914.

○ SITES WHERE SCREEN TRAPS WERE LOCATED.

■ MEDFORD, MASS., WHERE THE SPECIES WAS FIRST INTRODUCED - 1869 OR 1869.

Table VIII is here presented to show the annual advance of the moth before and after control was attempted. This indicates that the winds are chiefly responsible for the present conditions.

TABLE VIII.—*Spread of the gipsy moth in various directions by series of years from five years after its introduction at Medford, Mass., to 1914.*

Periods of years.	NE.	N.	NW.	W.	SW.	S.	SE.	Average spread per year by periods.
	Miles.	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Miles per year.*
1875–1890	15	10	5	10	6	4	3	0.5
1891–1899	5	4	5	4	4	5	4	.5
1900–1905	27	11	12	10	12	14	62	3.5
1906–1909	41	60	25	19	15	16	11	6.7
1910–1914	114	16	28	15	24	26	0	6.4
Total	202	101	75	58	61	65	80	.....
Average for 40 years	.....	.....	.....	.....	.....	.....	.....	2.3
Average spread per year in various directions	5	2.5	1.9	1.5	1.5	1.6	2	

It will be noted that the spread from the original center was very slow, averaging only 0.5 of a mile per year up to the beginning of the campaign in 1890. It was then held in control for a period of about nine years, during which time there was very little advance into new territory. The conditions in the old infested area were also much improved. This shows the necessity for keeping the moth under complete control if windspread is to be prevented. During the period from 1900 to 1905, when no work was being done, the moths spread at the rate of 3.5 miles per year. This had increased to 6.7 miles per year from 1906 to 1909, but this ratio has decreased to some extent in the last period up to 1914, inclusive.

The greatest distance gained in various directions has been to the northeast, an average of 5 miles per year for 40 years, which is the result of the favorable southwest winds. The combination of southeast and southwest winds during the dispersion period has carried the larvæ northward at the rate of 2.5 miles per year. The spread to the west, southwest, and south was accomplished at a slower rate, owing to the less favorable winds blowing in those directions.

SUMMARY.

In 1913, as a result of the several experiments conducted by using tanglefooted screens and cloth for traps, there were caught on 977 square feet 289 first-stage larvæ which had been borne by the wind one-eighth to 1 mile or more. In 1914 there were removed from 1,614 square feet of sticky surface 346 larvæ which had been blown from one-eighth to 13½ miles or more, as verified by the wind records taken at or near those points. Three larvæ were also taken from two large screens on the hills in New Hampshire during 1914.

Considering the great numbers of larvæ taken in these experiments, there can be no doubt that the wind is almost wholly responsible for the general spread of this insect in New England, notwithstanding the fact that many of the former publications teem with explanations of possible accidental or artificial spread by man and animals. The recent establishment by the Federal Horticultural Board of a quarantine on lumber products, Christmas trees, nursery stock, and stone moving from the infested territory, until inspection has been made, has greatly relieved the danger of a general distribution of the gipsy and brown-tail moths over the United States, but the sources of dispersion of the gipsy moth by the wind can only be lessened by the effectiveness of the parasites and predaceous enemies, together with hand methods of control. To prevent continual spread by the wind into new territory the badly infested areas near the border must be brought under control either by natural enemies, or hand methods, or both. Natural enemies, however, are now playing an important rôle in the control of this insect in the greater area of the inside infested territory.

The larvæ are sufficiently active and allow themselves to be transported by the wind at temperatures of 55° F. and above, and have been caught at wind velocities varying from 2 to 23 miles per hour, although more active spread takes place when the temperature ranges from 65° to 85° F. and when the velocity reaches 8 miles or more per hour. Larvæ are removed from their support and carried by sudden gusts of wind, whether they spin or not, when the temperature reaches 50° to 55° F., at which temperatures they often start crawling.

The records also show that larvæ have been caught at times when winds were blowing from all directions except the north—only a very few coming from the east, but the location of the screens along and near the coast materially affected this condition. By far the larger numbers were borne by combinations of the west winds as indicated on the screen at Merrimac, Mass., which was surrounded by a general infestation.

The general progress of the species since its establishment at Medford, Mass., at the rate of 5 miles per year to the northeast and at the rate of 3 miles per year westward from Providence, R. I., since its first appearance there in 1901 tends to verify the data that have been collected in connection with the screen experiments.

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